DESIGN OF A STEAM POWER PLANT

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I N T R O D U C T I O N.

In this Design of a steam Power Plant, particular attention has been made to the bus layout and the various control systems of the electrical apparatus used in generating and metering the electricity, with due attention to the rating of the steam and electrical apparatus.

The plant is designed for furnishing power to electric railways with a maximum output of 10,000 K.W. and an average curve for the day like that shown in page **four**. Approximately two thirds of the total output is used in high tension overhead transmission, being transformed from 6,600 volts to 66,000 volts for such purpose. Part of this power is to be used by Mr. Pfeifer in his transmission line, while the remainder is to be used for railway work in near by towns. The remaining third

is to be used in local Railway work, under ground cable being used for transmitting the electricity from the central station to the respective sub-stations.

The operating schemes are similar to those used by the Common Wealth Edison Company and Public Service Company of Northern Illinois, knowledge of these schemes having been obtained by the writer in his two years practical experience with said Companies.

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In planning the lay-out of a central station for generating electric power, many things have to be considered before a site can be selected on which to construct a money making Plant.

The first thing to consider would be a canvas of the proposed district to find out the possibilities of selling your current and the chances for future expansion in the surrounding towns. The kind of load that you will have, will determine to a great extent the type of apparatus that will have to be installed in your Plant.

Say that you have looked over the situation and find a condition something like this: The only town situated near running water, which in the first place, is a necessity to successfully operate a Steam Plant, is a town of say 30,000 people. The lighting of this town is taken care of by a local steam power plant which has made provision in its

construction only for taking care of the future lighting load. To take care of an electric railway system for the town, this Plant would have to construct a new power house with all new machinery, as the railway work would require 25 cycle current instead of 60 cycle. This would mean a big expenditure of money, and as stated before, their old power house has not the room for such additional apparatus, so this local company would not attempt the contract for only the railway load that they would get from the town. Say that you look the town over and find that a stock company has been organized which is willing to give you the load at a good paying price, with a guarantee of construction and consumption of 4,000 K.W. of your load.

In looking outside in the surrounding district you find that there is a company wanting to come in from a town say about fifty miles distant, that is willing to construct its own transmission line and sub-station, which will take an additional 2,000 K.W. of your load for railway work. You find two

other towns near by, say within fifty miles, that would take 1,500 K.W. each, if the proper transmission lines were run to them and the power furnished for railway and power work. Next you look at the surrounding country and find that it is used extensively for farming purposes with a possibility of reclaiming land by proper irrigation, and that enough prospective customers are available to make a transmission line pay. You could not afford to furnish electricity to a rural territory unless the conservatively estimated yearly revenue is equivalent to 50 percent of the cost of construction of the extension, including the usual overhead expenses. Contracts for rural work should be closed before the work is started and then for periods of not less than ten years and preferably for fifteen or twenty years. The rates should be made up of a fixed charge based on the maximum peak demand for a season, with an additional meter charge based on the peak demand per month. Irrigation pumping can be made desirable and profitable if a large installation is made to serve several land tracts in rotation.

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You find, after looking over the situation that you can profitably take over the contract for furnishing 1,000 K.W. rural power load.

This completes the load as shown by the load curve, while practically the entire amount included is a railway load.

Now this load would well be worth while building a central station to handle, and you decide to construct the plant.

The next thing to do is to find a suitable site for the plant. As there is a stream of water flowing through the town which continues to flow throughout the year so as to guarantee you fresh water for your intakes, for use as circulating water and boiler feed water. You find the most economical spot, say if possible at a bend in the stream, so as to take advantage of the natural lay-out for circulating water through your intakes, and build your plant as required by your respective load.

A Plant to approximately fill this demand has been designed in this paper.

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Selection and Rating of Units.

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The start in the design is made from the load curve which is given as a working basis. From the load curve the maximum load is seen to be 10,000 K.W. while the minimum is about 2,500. A four thousand K.W. unit is seen from the curve to be sufficiently large to carry the load from 11:00 P.M. till 6:30 A.M. Then one 4,000 K.W. and one 2,000 K.W. could carry the load from 6:30 A.M. till 4:00 P.M. By adding another 4,000 K.W. unit the load can be carried safely over the peak-load. This lay-out calls for two 4,000 K.W. and one 2,000 K.W. as the machines necessary to actually carry the running load, the three machines being used instead of one large one to carry the total load because a generator operates at greatest efficiency on full load so the rating of the machines are made so that each machine will be running at as near full load as possible while on the system. An extra 2,000 K.W. unit is used

as a reserve in case one of the units should be out of service for repairs. This will allow one of the 4,000 K.W. units to be taken out of service by operating all of the other units at the allowable 25 percent overload during the peak of two hours straight running. The machines chosen were, two 4,000 K.W. units, Westinghouse type, 6,600 volts, 3 phase, 25 cycles, and two 2,000 K.W. units of the same type, 6,600 volts, 3 phase, 25 cycles, all of the horizontal class, with the machines operating condensing with a boiler steam pressure of 165 pounds per square inch.

For future extensions of the Plant, space is left in the boiler room for installing two additional boilers or if needed, the end wall can be moved and space made for the additional boilers if desired, while machines of larger size may be installed in case of a material increase in load.

6,600 is selected for the generated voltage because it can be used, without being trans-

formed, in local railway work; also it forms a very good transmission voltage as the convenient ratio of 10 : 1 can be used in stepping it up to the over-head transmission lines. Then the insulation required for the generators is not too expensive for this voltage.

The Westinghouse turbines used are of the double flow or mixed type. The steam enters through nozzles into a two velocity stage impulse wheel, and from here it passes into a medium pressure parsons section; then the steam divides and passes through two low pressure Parsons sections one on each end of the Rotor.

Some of the advantages in using steam turbines as prime movers are: High efficiency; low first cost; minimum amount of labor; low depreciation and maintenance; small amount of oil required; freedom from vibration; low cost of buildings and foundations; uniform rotation, which is especially desirable in operating A.C. generators in parallel; can be started quickly; can be governed as closely as the reciprocat-

ing engine; full load can be thrown on or off instantaneously without in any way endangering the turbine; condensed steam is free from oil so that the water can be returned to the boilers, this being especially valuable where bad feedwater has to be used; simplicity of packing small number of bearings; ease in renewing parts; operates equally as well condensing or non-condensing; freedom from break downs owing to water in the steam; high economy at light loads; good regulation of generator, and high overload capacity.

Governing is accomplished by varying the steam supply. The curtis turbines operate by varying the number of nozzles by gradually closing and opening one after another and control being placed in the operating gallery, while the Westinghouse machines are governed by the puff method introduced by Parsons, where the inlet valve is so adjusted that it is constantly opening and closing and the amount of steam admitted in unit time is controlled by varying the length of time the valve remains closed.

Speed-limit devices which serve to automatically shut off the steam when the speed exceeds a certain value, are installed on all the machines, should the governing mechanism for any reason fail, to prevent the destruction of the machine.

In this type of turbine, where the speed is 1,200 R.P.M. or higher, flexible bearings are employed to absorb the vibration incident to the critical velocity. They consist of a nest of loosely fitting concentric bronze sleeves with sufficient clearance between them to insure the formation of a film of oil. The oiling system is made up of a supply tank, under pressure of from one to three feet of oil, from which the oil flows through the bearings, then through a cooler, the circulation being maintained by means of a pump.

The cost of the turbo-generator units based on pig iron at $20.00 per ton; For the 4,000 K.W. units the cost price would be about $21.00 per K.W. and for the 2,000 K.W. $25.00 per K.W.

There is a flexible connection between the turbines and generators for the purpose of providing for any inequality in the wear of bearings, to permit of axial adjustment of the turbine spindle, and to allow for expansion, also gives means of disconnecting the turbine from the generator in case of repairs.

The boilers are arranged back to back with the turbine units. The size of the steam pipes, based on a mean effective pressure of 40 lbs. per sq. in. and 6,000 ft. per minute as an average velocity, were determined by the formule:-

$$P = 6d^2$$

where d = the diameter of the pipe in inches, and P = the horse power of the engine; Allowed 3 in. expansion per 100 ft. of piping. Steam traps are provided in the piping at places of likely condensation and the condensed steam drained into the hot well by means of small pipes. All pipes as well as joints are covered with a good quality of lagging. Used the 85% magnesia lagging 2-1 in. sectional,

which offers a saving of 88.7% at 160 lbs. at an average thickness of 2.24 in.

Calculations for Pipe diameters:-

$$d = \sqrt{\frac{P}{6}}$$

From main to 4,000 K.W. turbine

$$d = \sqrt{900}$$

$$= 30''$$ This calculation is made on the assumption that one T.H.P. requires 0.1375 sq. in. of steam pipe area.

The diameter of the exhaust piping is fixed by the engine builder as one which is sufficient to prevent undue back pressure, case Iron pipes, joined by flanges are used for the exhaust piping of the condensing system, the piping being installed so that the drainage is toward the condenser, making especially good joints so as to shut out the air from the condensers.

A relief valve, called the atmospheric relief, is placed in the piping to the condenser in such a way as to open the exhaust to the air in case

the vacuum fails and a pressure is maintained in the condenser. The size of this pipe connected to the valve is sufficient to take care of the exhaust steam or 2. ft. in diameter.

The Babcock and Wilcox boiler was used and they were arranged in pairs with two pairs included in one battery. To find out the boiler H.P. required to furnish the total steam for the 10,000 K.W. output. Visits were made to Blue Island, Illinois Plant of Public Service Company, to Grove Street plant of C. E. Company to the Fisk and Quarry St. plants of the C. E. Company, and it was found that at Grove Street there were eight B. & W. 500 H.P. boilers for 16,000 K.W. rating of electrical output. At Fisk Street each 10,000 K.W. unit uses a battery of eight 500 H.P. boilers. At Quarry street a battery of eight 550 H.P. boilers is used for each unit of 12,000 K.W. rating. So the conclusion was reached that for the 10,000 K.W. output, eight boilers, or two batteries should be used, the rating of each boiler being 500 H.P. Using the installation at

Blue Island as a standard of comparison; the following dimensions were used in the installation:

Distance between batteries------------ 6'
Width of space behind boilers----------20'
Coal chutes per battery--------------- 4
Height of basement---------------------12'
Thickness of floor-------------------- 5"
Distance between I beams in floor------ 4'
Distance between Boilers and end wall-- 6'
Support of boilers (basement) made of brick.

The stoker driver motor is in the middle of the boiler room one on each side, the power being transmitted to the stokers by means of line shafting and belts. There is also a set of steam driven stoker engines to be used in emergency cases.

16" I beams support the floor and are situated in the basement.

The opening under the boilers is walled up only in the ash compartment.

For the four pairs of boilers used, two stacks have been used, or four boilers per stack. The stacks are five ft. in diameter, made of steel and lined with brick and cement four inches thick at top and slightly thicker at the bottom, with calcula-

tions as follows:

$$H = \text{Height} = \frac{(\,0.3\ \text{H.P.}\,)^2}{E}$$

where E is effective area.

The coal handling apparatus consists of first one unloading crane, which unloads the cars of coal in the train shed where the coal falls into pits out of which it is taken directly into a crusher in the basement. A bucket conveyer passes through the basement for each set of stokers and ash pits, passing under the crusher and up at each end to the roof where it extends over the stoker pits. Thus the coal and ashes may be conveyed to their desirable places.

The auxiliary apparatus consists of the proper capacity machines including for each generator, one air pump, one circulating pump, one hotwell pump and the proper oil and seep water pumps; while there are two boiler feed pumps, each designed to carry the plant, one always being in repair in case of emergency. A closed type of surface heater is used to heat up the

exhaust water for the turbines and all the boiler feed water, an oil strainer being placed at its entrance to remove the oils from the boiler water. The Boiler feed pump is placed between the Feedwater heater and the boilers to make pressure on the boilers and not on the heater. All the auxiliaries are steam driven except the hot well pump which is driven by a non commutating motor heavily insulated as it is often flooded and should do work under water.

One of the most vital parts of the plant is the exciter system and provision should be made here for any possible emergency. One steam exciter, with capacity to carry the plant is used, and two motor exciters whose combined rating will carry the plant. One motor exciter may be used at full load when the load on the turbines is light. In case of complete shut down, excitation for the plant can be obtained from the steam exciter.

THE ELECTRICAL LAY-OUT.

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The electrical units used, being four in number, generate the electricity at 6,600 volts. From the machines the lines run through K^2 oil switches to the low tension buses directly. There are two such buses with suitable switching arrangements for using either or both with whatever machines desired, making it possible to clean the buses, having one entirely isolated from the others by means of opening clips and oil switches. By a study of my wiring diagram these operations can be traced through.

The low tension bus serves two purposes, that of supplying the low tension lines with power, also of feeding into High tension lines directly through transformers.

All high tension switching is done through type H^6 oil switches, which have the big advantage of having both the clips on the line and bus sides of the switch situated side by side thus making

the chances for mistakes less likely.

The transformers used are of the single phase type, using three for each line with delta connected secondary, so that if one should be burned out, the open delta arrangement can be used at part load until another one can be substituted in its place.

The busses and machines are fully protected from line trouble by automatic oil switches. All the oil switches are automatic except those on the generators and Bus ties.

As modern generators are built with 5% reactance, the machines contain enough reactance to make it unnecessary to insert more between them and the busses.

The electro lytic cell type of lighting arrester were used and placed on only the high tension overhead lines with proper disconnects and reactors as in wiring diagram.

The meters used on each generator consisted of three integrating watt meters, three indicating watt meters, one ammeter, one volt meter

with switch to test each phase, one frequency meter, one D.C. field ammeter and one D.C. volt meter. As the power is all used for Railway work, the metering is lighter than it would be for unbalanced loads.

The line instruments consist of three integrating watt meters, one ammeter, one indicating watt meter, and protective relays on each phase, the integrating watt meters being placed on different current transformers from those used for the relays.

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List of Electrical Apparatus.

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10	Thompson Indicating Wattmeters, G.E. Co.
11	Time Limit Relays, Amperes 5, G.E. Co.
32	Thompson Watthour meters (1 wire - 1 phase) Amperes 5, Volts 110, Cycles 25
9	Bristol Recording Ammeters, By Bristol Co.
4	Generator field Rheostats (motor)
3	Exciter field Rheostats (magnet)
3	Recording Wattmeters, D.C. 110 Volts
27	K^{2} Oil switches
7	H^{6} Oil switches
66	Current Transformers (various ratings)
32	Potential Transformers
9	Solenoid operated circuit breakers
3	3000 K.W. Transformers (6600-66000)
3	100 K.W. Transformers (6600-220-110 Volts)

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9	D.C. Ammeters (Western)
2	D.C. Voltmeters (Western)
13	A.C. Ammeters (Thompson)
1	Synchroscope
4	Frequency meters
2	Westinghouse (6600 Volt- 3 phase)25 Cycle, 4000 K.W. generators
2	Westinghouse 6600 Volt, 3 phase, 25 Cycle, 2000 K.W. generators
2	Motor generator sets. Output 60 K.W.
1	Generator, Steam driven, 120 K.W.
1	Storage Battery, capacity 1000 Amperes for 1/2 hr.
	All wiring for operating work of #10 B. & S Wire
1	7 Panel Switchboard with necessary switches.

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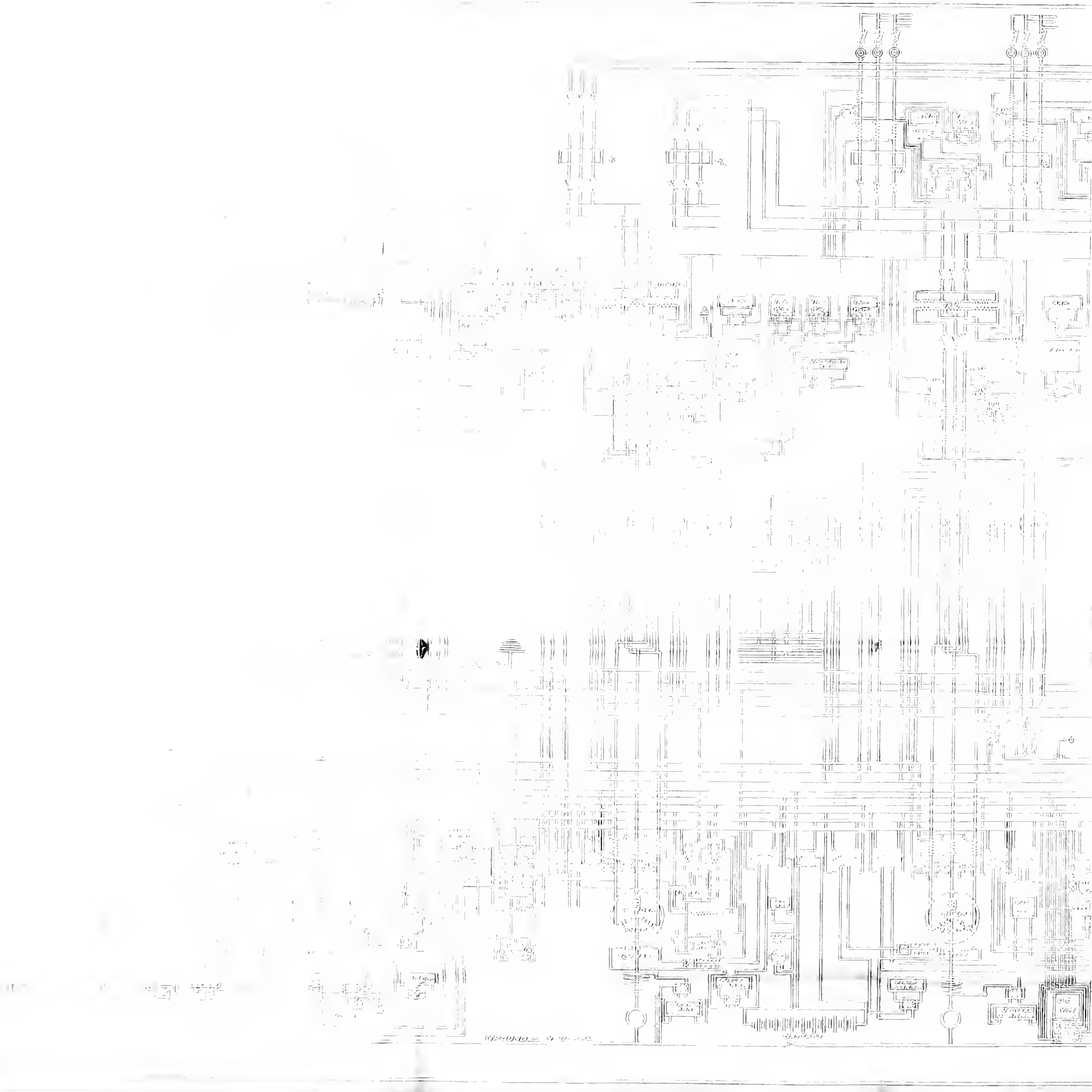

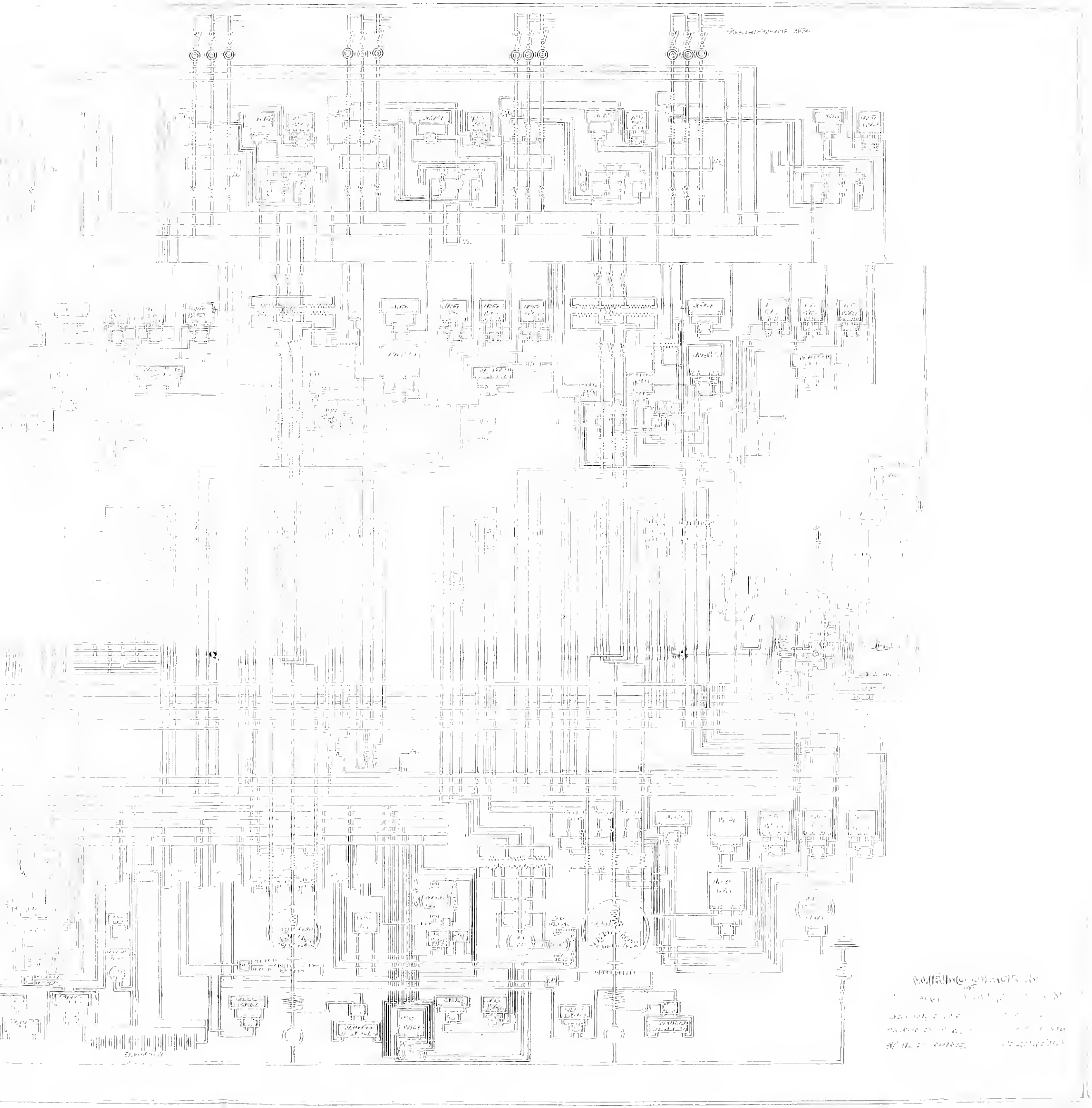

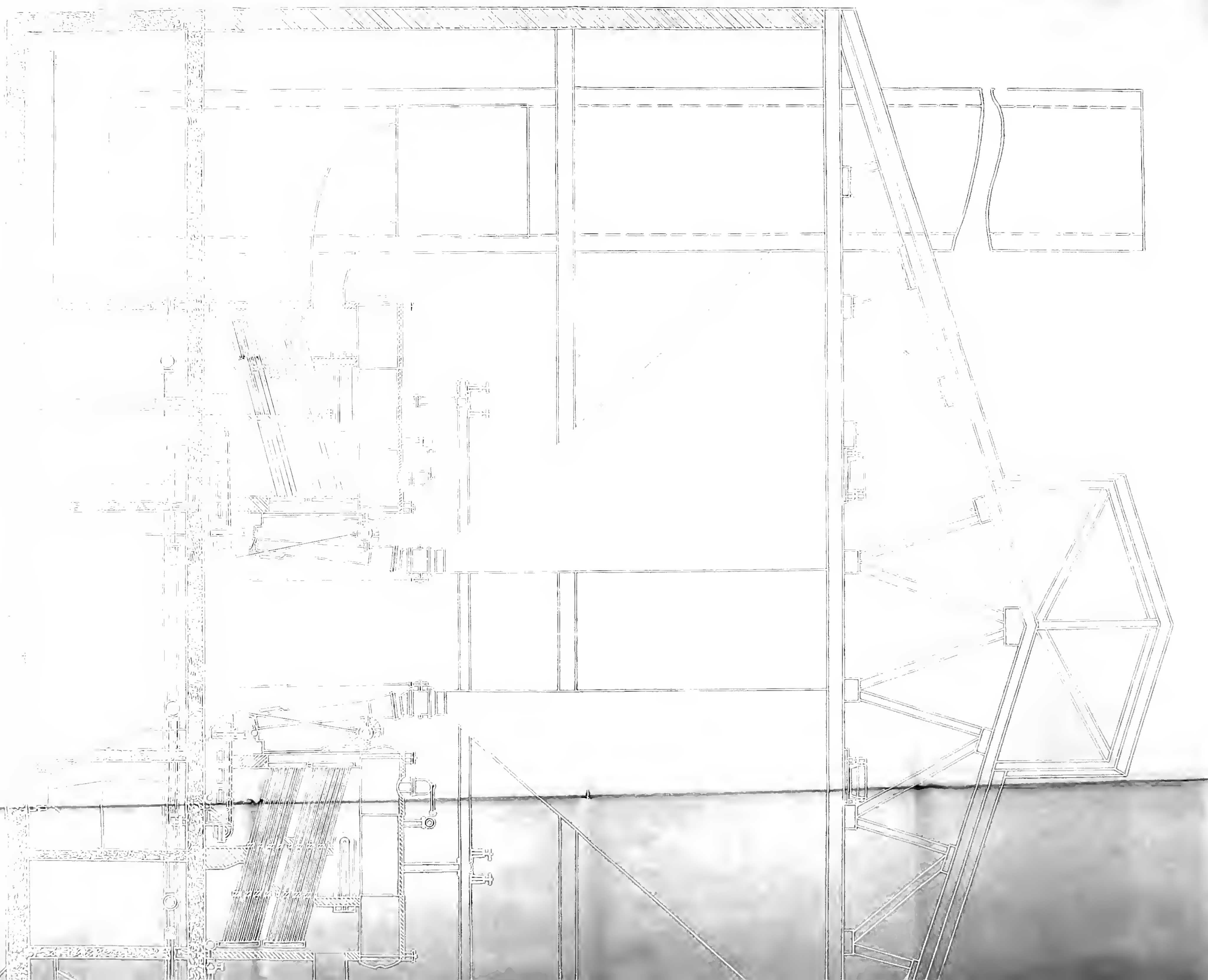

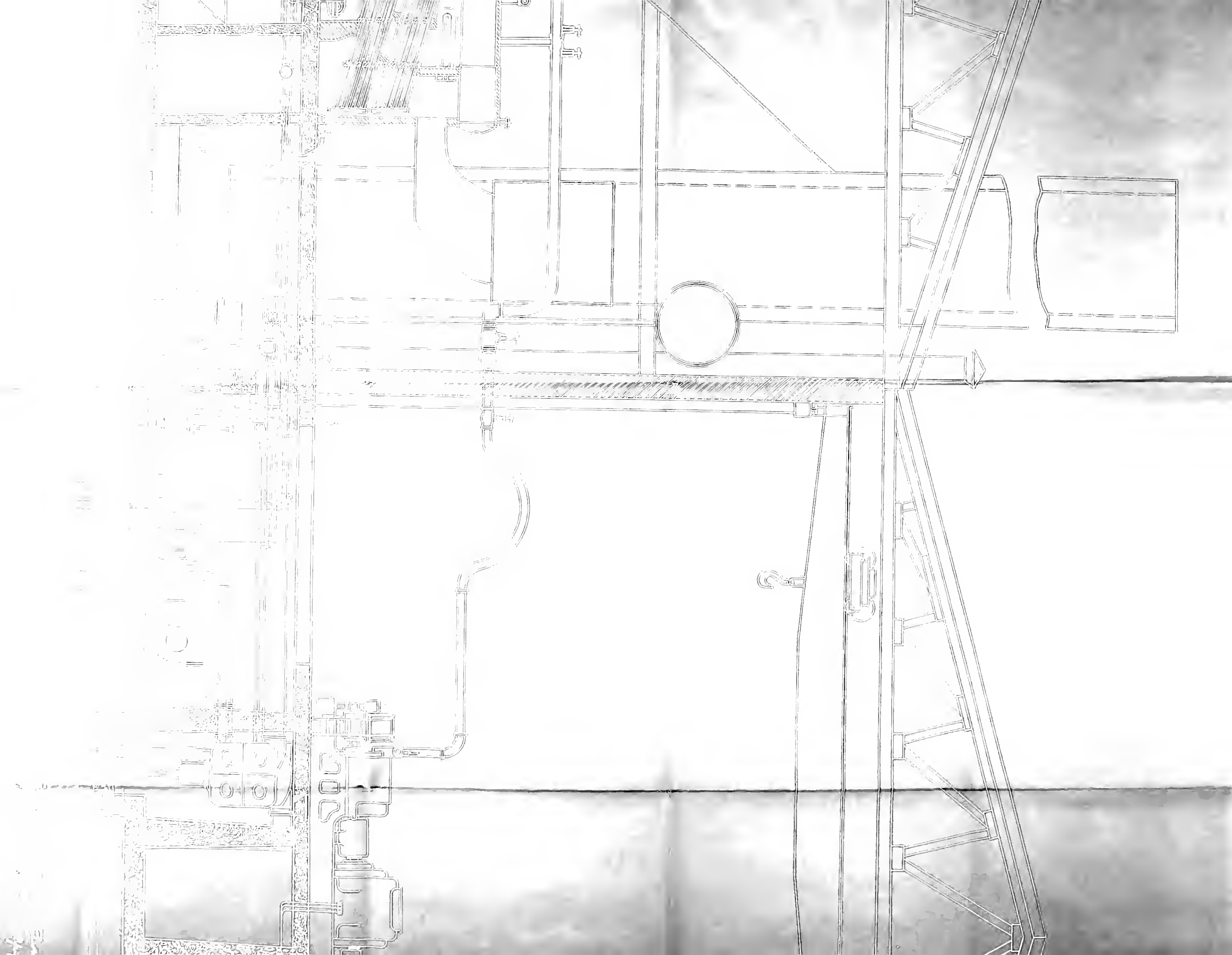

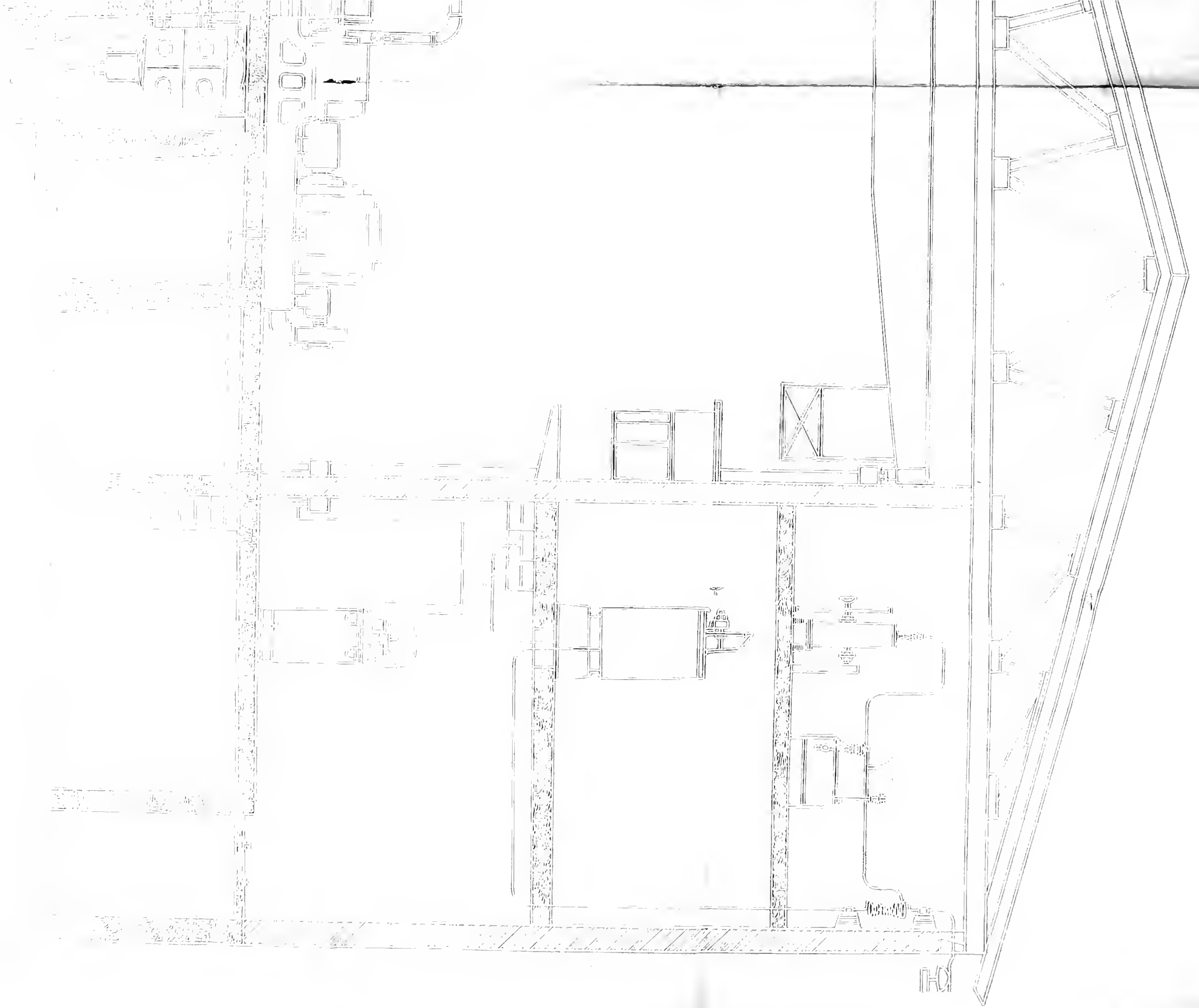

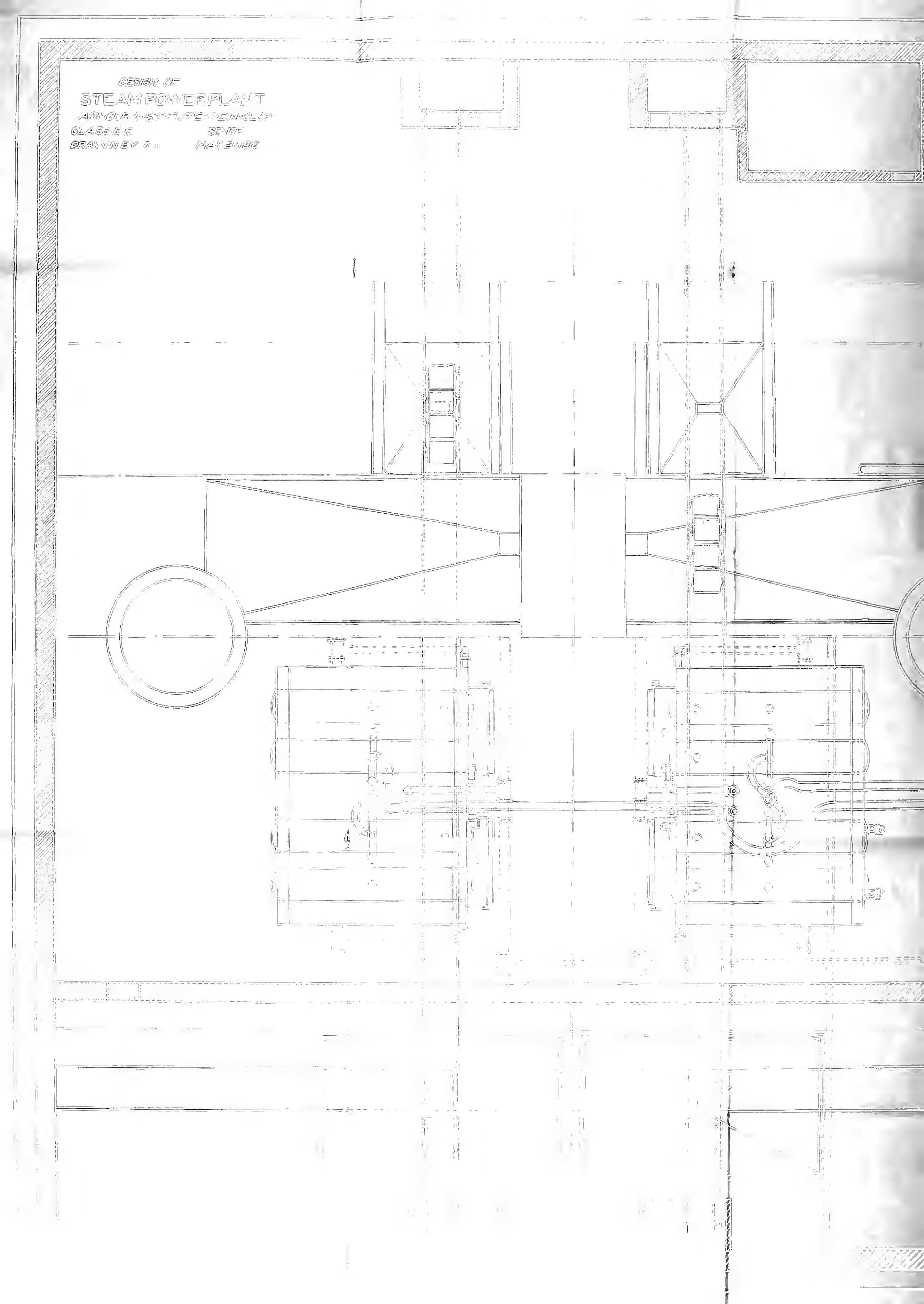
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